MASSACHUSETTS COASTAL COMMERCIAL LOBSTER TRAP SAMPLING PROGRAM MAY-NOVEMBER, 1994

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ABSTRACT

This is the Massachusetts Division of Marine Fisheries fourteenth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. During the period of May through November, 1994, seventy-six sampling trips were made aboard commercial lobster vessels. A total of 34,309 lobster was sampled from 13,584 trap hauls. The catch rate of marketable lobster, 0.966 lobster per trap, was 44% higher than the 1993 index, 0.671. The proportion of females ovigerous, 10.7%, was lower than in the previous year (14.3%). The coast-wide fishing mortality estimate, 1.41, was similar to the 1993 index, 1.48. Exploitation rate, 0.68, changed little from 1993 while mean carapace length of marketable lobster, 88.8 mm and mean size of egg-bearing females, 86.3 mm, increased by 0.4 mm and 1.0 mm, respectively. The percentage of culls continued to increase from the 1992-93 level. Less than 1% of the lobster sampled from traps were dead.

An index of pre-recruit abundance was created using data from our sea sampling database. The catch rate of lobster in the pre-recruit size class provided the basis of the index. The index was calculated from a multiple regression of log transformed catch rates with the following factors: month, year, lobsterman. The back-transformed regression coefficient associated with the factor "year", adjusted for the effects of the other analyzed factors, provided the index of pre-recruit abundance. The relationship between the index and the territorial catch in the following year was modelled using a power function. The resulting equation was used to calculate predicted landings which differed from the actual landings for the years 1981-1994 by 0.3 to 14.6% with a mean difference of 6.7%.

A time series of data from our bottom water temperature monitoring program is presented for seven locations in Buzzards Bay and Cape Cod/Massachusetts Bay.

INTRODUCTION

This is the Massachusetts Division of Marine Fisheries (DMF) fourteenth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. Since the lobster resource supports the most economically important single-species fishery in Massachusetts coastal waters, a long-term coastwide lobster monitoring program yielding biological and catch per unit effort data was devised and initiated in Massachusetts in May, 1981. A sea sampling/survey design was chosen by which both catch per unit effort and biological data could be collected temporally and areally with sufficient precision for stock assessments. The objective was to assess variations in population parameters due to environmental factors, fishing pressure, and regulatory changes.

Data collected during the 1994 coastwide commercial lobster trap sampling program are summarized below. Parameter trends occurring during the 1981-1994 study period are presented.

STUDY AREA

The study area is primarily defined by the Massachusetts territorial sea, except where lobstering activities of cooperating commercial lobstermen exceeded territorial boundaries (Figure 1). Territorial waters total 5,322 sq km (2,055 sq n mi), of which an estimated 60% is considered major lobster habitat. Six sampling regions, Cape Ann, Beverly-Salem, Boston Harbor, Cape Cod Bay, outer Cape Cod, and Buzzards Bay, were chosen for coverage of the major lobstering regions of the state. For convenience, these regions are depicted in Figure 1 as generalized hatch-marked areas wherein lobster gear sampled may be discontinuously distributed.

SAMPLING PROCEDURE

Sampling of coastal waters was accomplished by monitoring catches during the normal lobstering operations of volunteer commercial lobstermen in each designated region. Multiple lobstering operations were observed to reduce bias from varying degrees of lobstering skill and to enhance areal coverage. Pot-sampling trips were day trips, conducted a minimum of once per month per region during the major lobstering season, May-November.

Utilizing portable cassette tape recorders, sea samplers recorded carapace length (to the nearest mm); sex; and condition, including the degree of shell hardness, culls and other shell damage, external gross pathology, mortality, and presence of extruded ova on females (ovigerous). Catch in number of lobster, number of trap hauls, set-over-days, trap and bait type were also recorded. Trap locations were recorded from LORAN and plotted on nautical charts. Depth information was then acquired from the charts as a coast-wide standard to avoid variability from tidal fluctuations.

ANALYTICAL PROCEDURES

Data were computer coded and keypunched with a microcomputer data entry program. The data base was subsequently transferred for analysis to the National Marine Fisheries Service's Digital Equipment Corporation VAX-11/780 computer system at the Woods Hole Oceanographic Institution. A computer auditing process was used to uncover keypunch and recording errors and statistical analyses were performed with SPSS (Nie 1983) statistical sub-programs.
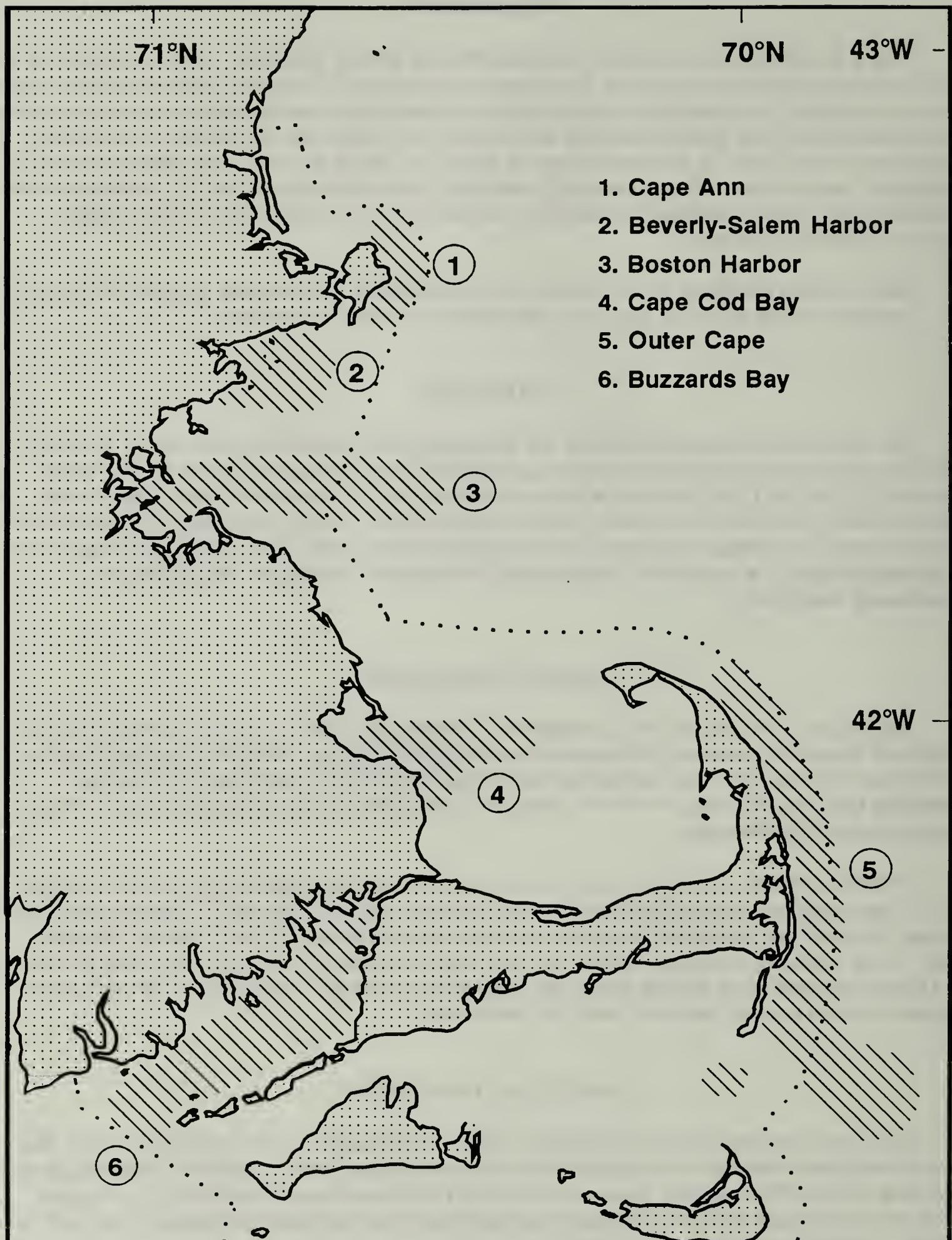
Figure 1. Map of Massachusetts with six sampling regions (hatch-marked) and territorial sea boundary (dotted line) indicated.

71°N 70°N 43°W –

1. Cape Ann
2. Beverly-Salem Harbor
3. Boston Harbor
4. Cape Cod Bay
5. Outer Cape
6. Buzzards Bay

42°W –

Because parameter means exhibit significant regional and monthly variation, an areal and temporal data weighting scheme was incorporated into analytical software. As a result, each month's data contribute equally to regional parameter means which are weighted by area in square nautical miles to generate coastwide means.

Unless specified otherwise, the terms "legal" or "legal sized" lobster include all lobster in the carapace length category $\geq$ 82.6 mm. The marketable segment of this category, which excludes ovigerous females, is analyzed separately and referred to as "marketable lobster". The sublegal length category includes all lobster < 82.6 mm.

The catch rates of marketable lobster are expressed as CTH'_3. This is catch per trap haul standardized to 3 set-over-days (Estrella and McKiernan 1989).

Estimates of total instantaneous mortality (Z) and total annual mortality ($A = 1-e^{-Z}$) were computed by two methods which produce extremes in the possible range of estimates. The method of Gulland (1969) requires computation of the regression line slope of natural log transformed numbers at estimated age (15% molt groups, 14% for Buzzards Bay, were derived from tagging data). Beverton and Holt's (1956) process employs von Bertalanffy Growth Equation parameters (from Fair 1977) and mean and minimum length of exploitable sizes.

Estimates of fishing mortality (F) were calculated with cohort analysis (Pope 1972, Jones 1974). Rates of exploitation were calculated with the equation $u = FA/Z$, where F = fishing mortality, A = total annual mortality, and Z = total instantaneous mortality.

Lobster landings data were derived from lobstermen's catch reports which are compiled annually by the DMF Commercial Fisheries Statistics Project.

Since current management strategy stresses uniform coastwide regulations, all data are grouped for a coastwide analysis. However, the uniqueness of the Massachusetts coastline, its role as a temperature barrier which profoundly affects many marine species (Colton 1964), and the influence of offshore lobster stocks on the inshore resource mandate a regional data treatment as well.

RESULTS AND DISCUSSION

Commercial Lobster Sampling

During the period of May through November, 1994, seventy-six sampling trips were made aboard commercial lobster vessels in Massachusetts coastal waters. A total of 34,309 lobster was sampled from 13,584 trap hauls.

The 1994 coastwide mean catch per unit effort index (CTH'_3), 0.966 marketable lobster per trap, was 44% higher than the 1993 index, 0.671 (Appendix Table 1). Total Massachusetts commercial landings, 16,139,690 lbs, increased by 11.8% from 1993. Landings from territorial waters, 9,792,271 lbs, increased by 7.3%. Landings and catch rate trends are depicted in Figure 2. The catch rates of sublegal lobster declined significantly between 1993 and 1994 (Appendix Tables 2 and 3).

Of all females sampled during 1994, 10.7% were ovigerous compared to 14.3% in 1993 (Appendix Table 4). Trends in CPUE of ovigerous females also declined and are depicted in Figure 3 (Appendix Tables 4-6).
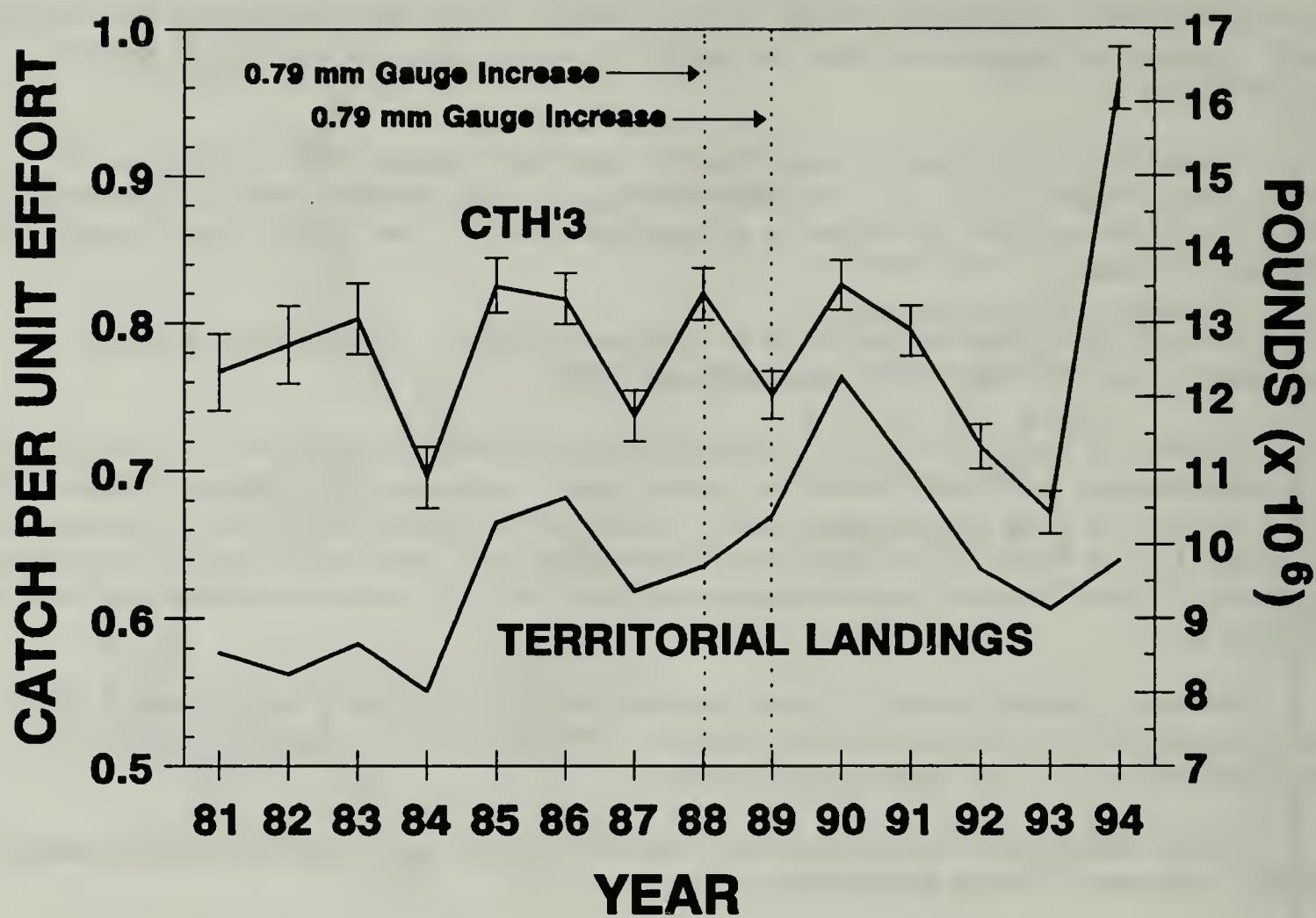
Figure 2. Catch per unit effort of marketable American lobster from commercial trap sampling and Massachusetts lobster landings from territorial waters, 1981-1994.

Approximately 93% of the legal catch in our inshore regions (Cape Ann south through Cape Cod Bay and Buzzards Bay) was comprised of new recruits (83 mm-94 mm CL), i.e., lobster which recruited to the legal size range during their most recent molt (Appendix Table 7). This index of the effect of fishing pressure on the size frequency was unchanged from 1993. The index fluctuated from 60% during the two years for the primarily offshore migrant lobster sampled east of Cape Cod. Estimates of total mortality (Z) for inshore Gulf of Maine regions (Z = 1.48-3.34, A = 77%-96%) and Buzzards Bay (Z = 2.85-3.58, A = 94%-97%) depict a heavily exploited resource while those for the outer Cape Cod region (Z = 0.79-0.92, A = 55%-60%) indicate that a lower level of fishing pressure was exerted on this lobster group (Appendix Tables 8a and 8b).

Estimates of instantaneous fishing mortality (F), the proportion of all deaths which are attributed to fishing, ranged from 0.68 off outer Cape Cod to 2.31 in Buzzards Bay (Appendix Table 9). Exploitation rates (u), i.e. the fraction of the population that is removed by fishing, were similar to 1993 data (Appendix Table 10).

The relationship between fishing mortality, rate of exploitation, and mean lobster size is depicted in Figure 4. Carapace length exhibited a downward trend as fishing mortality and exploitation rates increased through 1987. Thereafter carapace length increases of 0.7 mm occurred in 1988 (mean size = 88.2 mm) and 1989 (mean size = 88.9 mm, Appendix Table 11) which reflected the similar numerical change in the minimum legal size during those years. Thereafter carapace length fluctuated downward. Fishing mortality
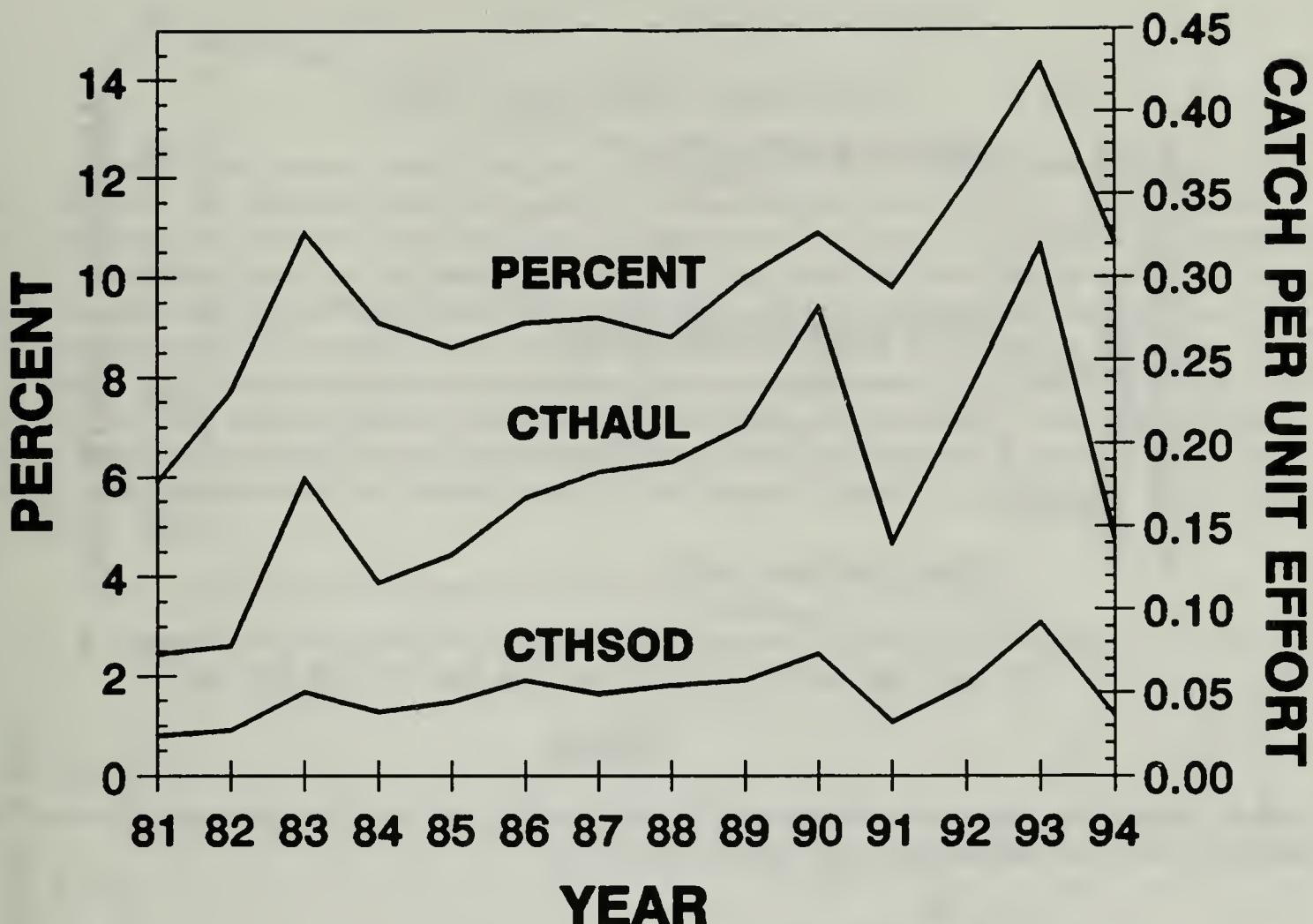
Figure 3. Relative abundance of ovigerous female American lobster in percent of total females and catch per unit effort, Massachusetts coastal waters, 1981-1994.

rates edged upward to a time-series high of 1.48 in 1993 for all regions combined while exploitation rates appeared to stabilize. In 1994, carapace length increased slightly while fishing mortality and exploitation rate decreased. The relative change in size frequency between 1993 and 1994 is depicted by the overlay in Figure 5.

Sublegal sized lobster averaged 77.5 mm carapace length during 1994 compared to 76.9 mm during 1993 (Appendix Table 12). The mean size of all ovigerous females increased from 85.3 mm in 1993 to 86.3 mm in 1994.

The percentage of culls (lobster with one or both claws missing or regenerating) among all lobster sampled fluctuated upward from 20.3% in 1993 to 21.9% in 1994 (Appendix Table 14). The cull rates for legal and marketable size groups increased substantially while that for sublegal size groups increased only slightly from the previous year's index (Appendix Tables 15-17). The cull rate for Buzzards Bay increased substantially and nearly doubled for legal and marketable size groups.

The coast-wide incidence of lobster found dead in traps was 0.22%. This was similar to that of the previous year (Appendix Table 18) and is considered to be acceptably low.
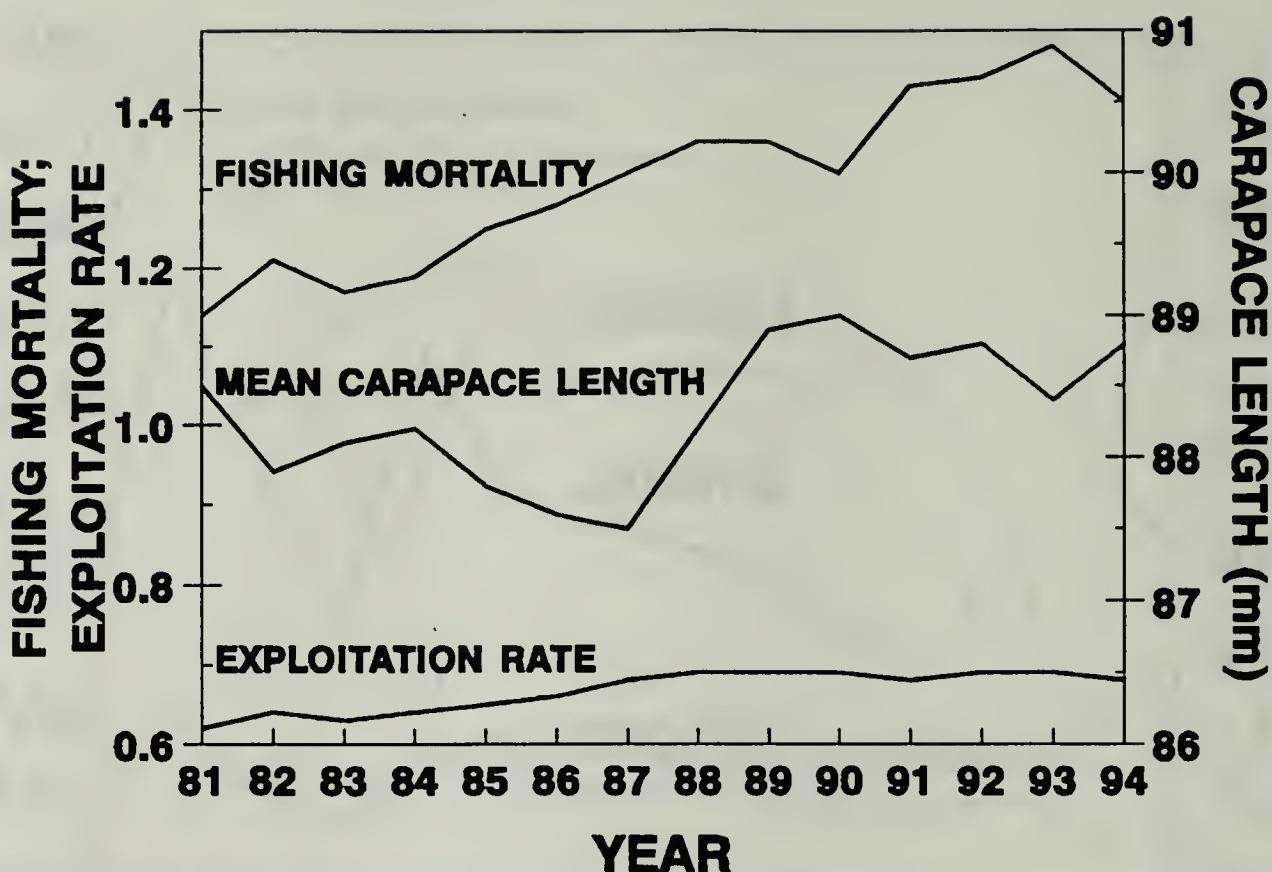
Figure 4. Relationship between exploitation rate, fishing mortality, and mean carapace length of marketable American lobster, Massachusetts coastal waters, 1981-1994.
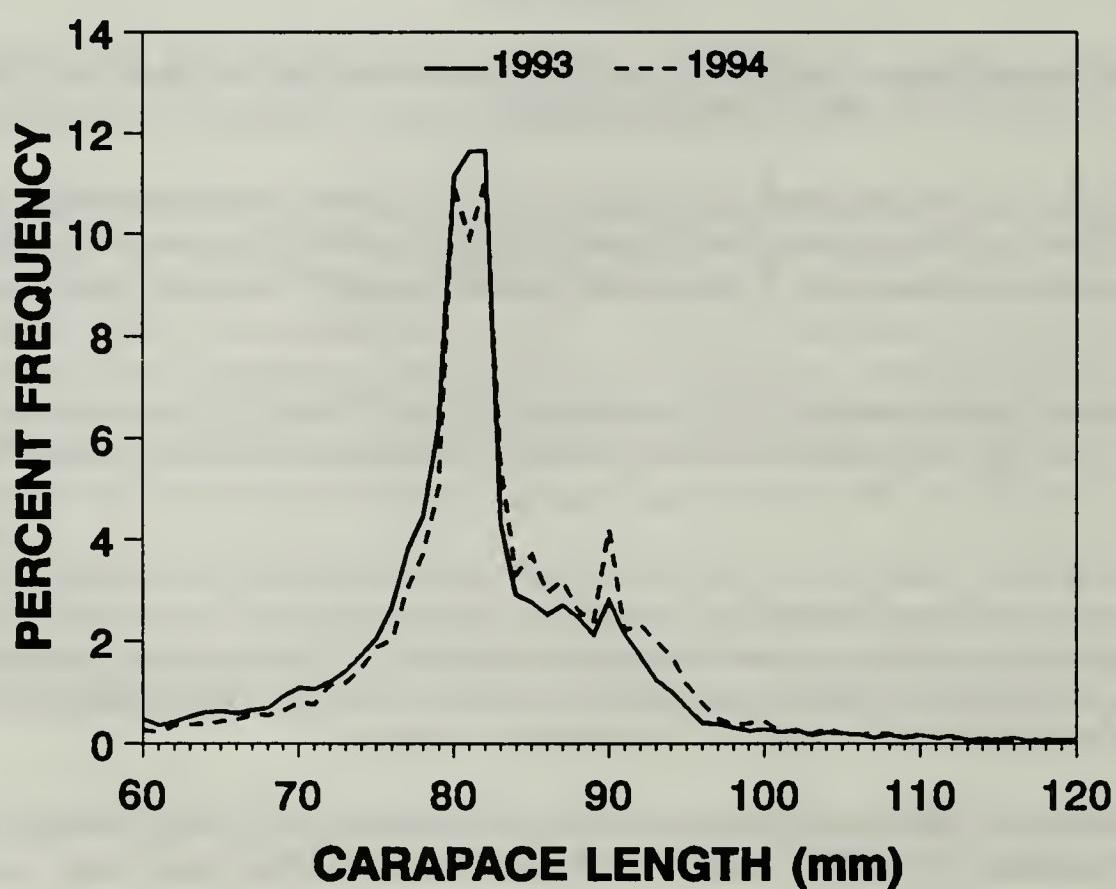
Figure 5. Length frequencies of trap-caught American lobster, Massachusetts coastal waters, 1993-1994.

INDEX OF PRE-RECRUIT ABUNDANCE

Using data from our sea sampling program, we created an index of abundance for pre-recruit lobster. The catch rate (number caught per trap haul) of lobster in the pre-recruit size class (68-80 mm carapace length for the years 1981-1987; 69-81 mm for 1988; and 70-82 mm for 1989 and later) provided the basis of the index. The index was calculated from a multiple regression of logarithmically transformed catch rates with the following factors: month, year, lobsterman. Other factors including soak time, bait, and trap type were incorporated in the preliminary regressions but failed to improve the fit and so were excluded from the model. The back-transformed regression coefficients associated with the factor "year", adjusted for the effects of the other analyzed factors, provide the index of pre-recruit abundance. This approach using regression/ANOVA modelling in the standardization of catch rates has been used successfully to create indices of juvenile abundance in the Western Australia rock lobster (*Panulirus cygnus*) fishery (Caputi and Brown, 1986).
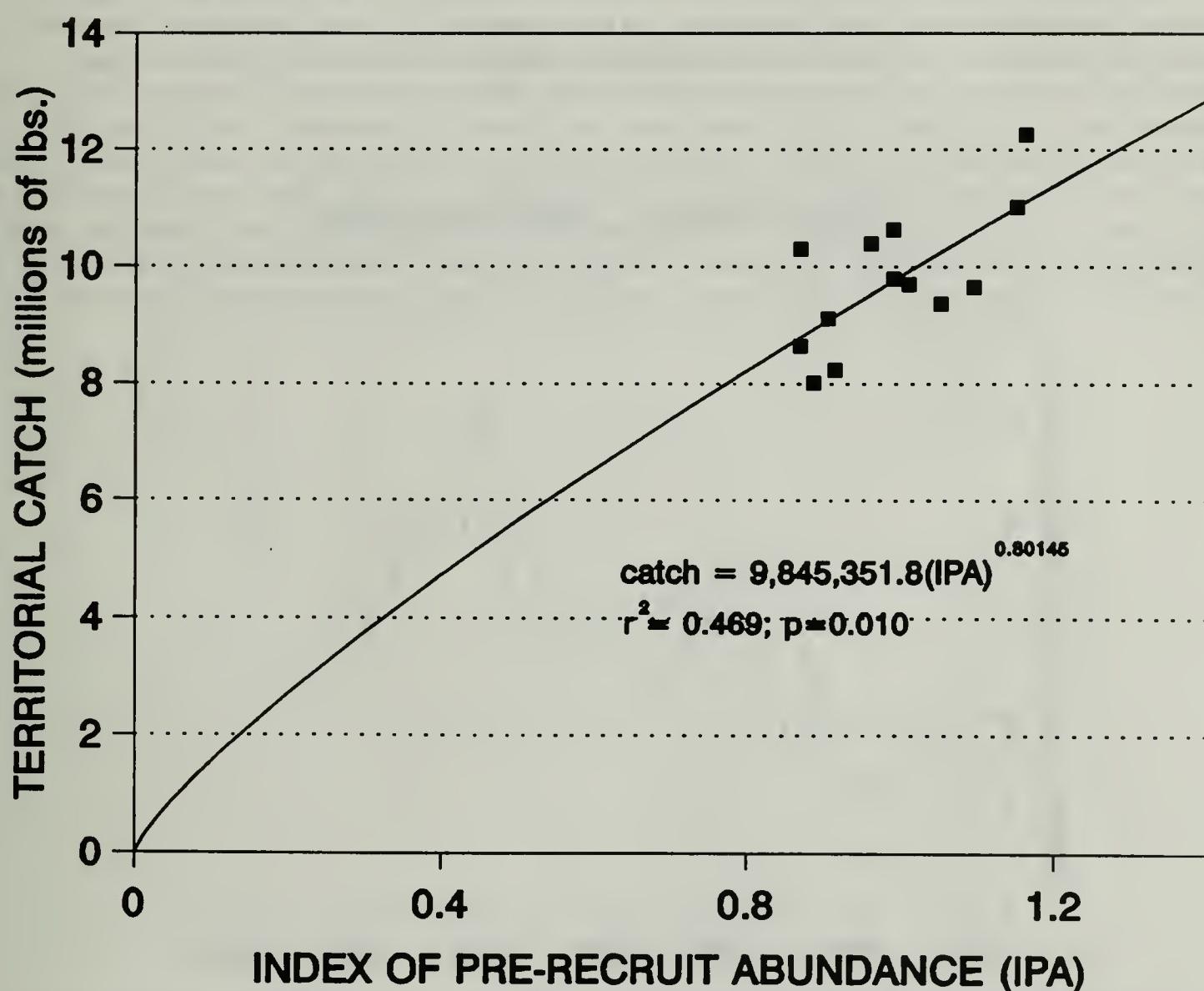
Figure 6. Relationship between the index of pre-recruit abundance and Massachusetts territorial catch one year later.

The relationship between the index of pre-recruit abundance (IPA) and the territorial catch in the following year (Figure 6) was modelled using a power function resulting in the following equation:

$$\text{Catch}_{t+1} = 9,845,351.8(\text{IPA}_t)^{0.80145}$$
$$r^2 = 0.469; \quad p = 0.010$$

where Catch_{t+1} = territorial catch in year $t+1$
IPA_t = index of pre-recruit abundance in year t

This equation was used to predict territorial landings. The relationship between predicted territorial landings and actual territorial landings is shown in Figure 7. The predicted values differed from the actual values by 0.3 to 14.6% with a mean difference of 6.7%.

The relatively tight fit between predicted and actual landings (r=0.70, p=0.008) indicates the model provides modest predictive power for territorial landings. The fit improves in the years after 1987, with especially close fits in 1992 and 1993. The model predicts a very slight decrease in territorial landings for 1995 to 9,688,799 lbs.

This model is simplistic in that it does not consider all the sources of variation such as annual temperature fluctuations and regional differences. An improvement in fit could probably be gained by conducting the analyses on a regional basis but a predictive index with statewide application is more desirable. Future efforts at fine tuning the index will include adding a temperature factor into the multiple regression.
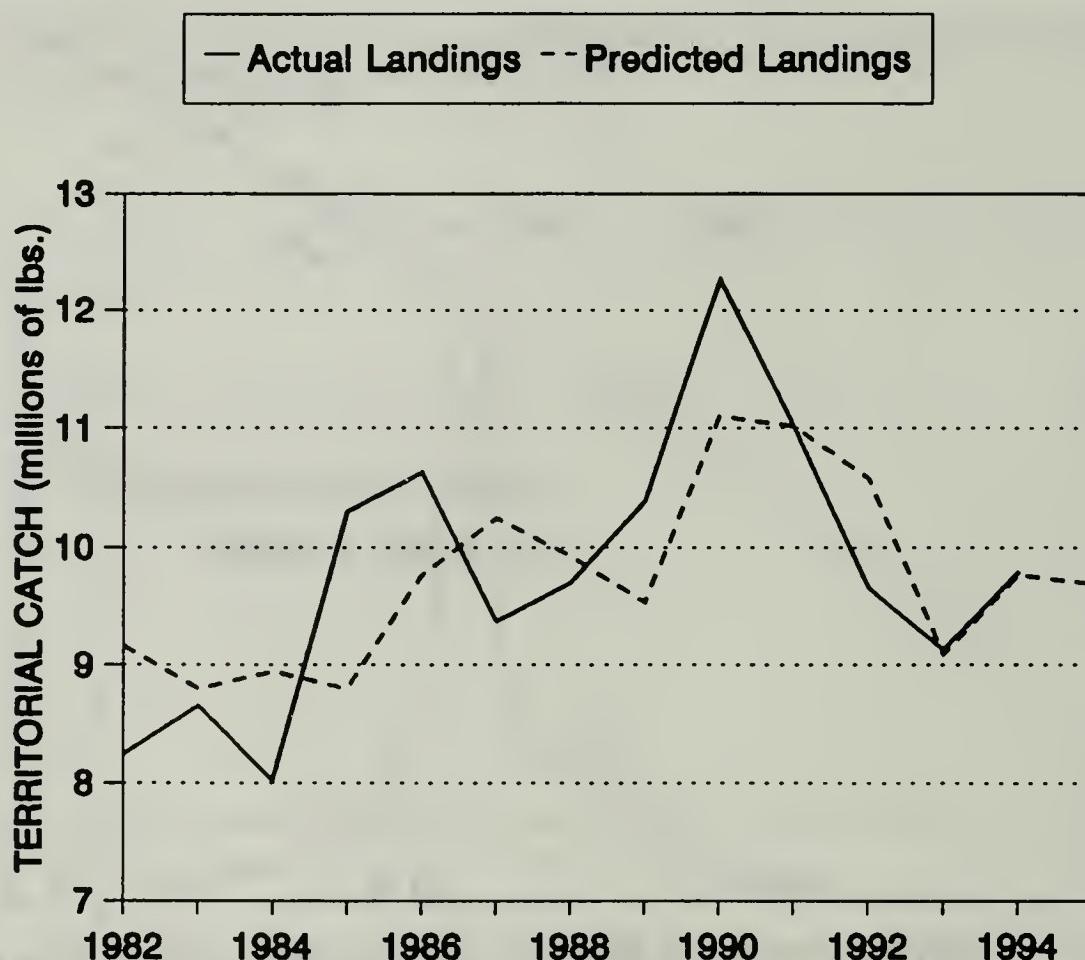
Figure 7. Relationship between predicted territorial landings based on the pre-recruit abundance index and actual territorial landings.

WATER TEMPERATURE TIME SERIES

In 1985, a coastal bottom water temperature monitoring project was initiated. Temperature monitors (RYAN Tempmentor) have been deployed for various lengths of time at several sites in Cape Cod Bay, outside Boston Harbor, and Buzzards Bay (Figure 8). The longest time series of bottom temperatures is from Cleveland Light in Buzzards Bay. The last monitor to be deployed was at Rocky Point, off Plymouth. The Rocky Point, Manomet Point, *Endicott*, and *Mars* sites represent the 0-30 ft., 30-60 ft., 61-90 ft., and 91-120 ft. depth strata, respectively, in Cape Cod Bay. The *Romance*, off Boston Harbor, and Buzzards Bay Tower sites are located at 70-80 ft. and provide data from the north-south extremes in our series. The Cleveland Light monitor is located in 30 feet of water. Monitors are retrieved and replaced annually by divers. Although the time series contained data from seven monitors at one point, we currently collect data from only six sites because the monitor at the Endicott site was lost and has not been replaced. Figures 9 and 10 present the bottom water temperature at sites in Buzzards Bay and Cape Cod Bay/Massachusetts Bay, respectively. Figure 11 provides a comparison between the annual mean bottom temperature at Cleveland Light, Manomet, *Mars*, and *Romance* and the annual mean surface temperature at Boston and Woods Hole provided by NOAA/NOS.

ACKNOWLEDGEMENTS
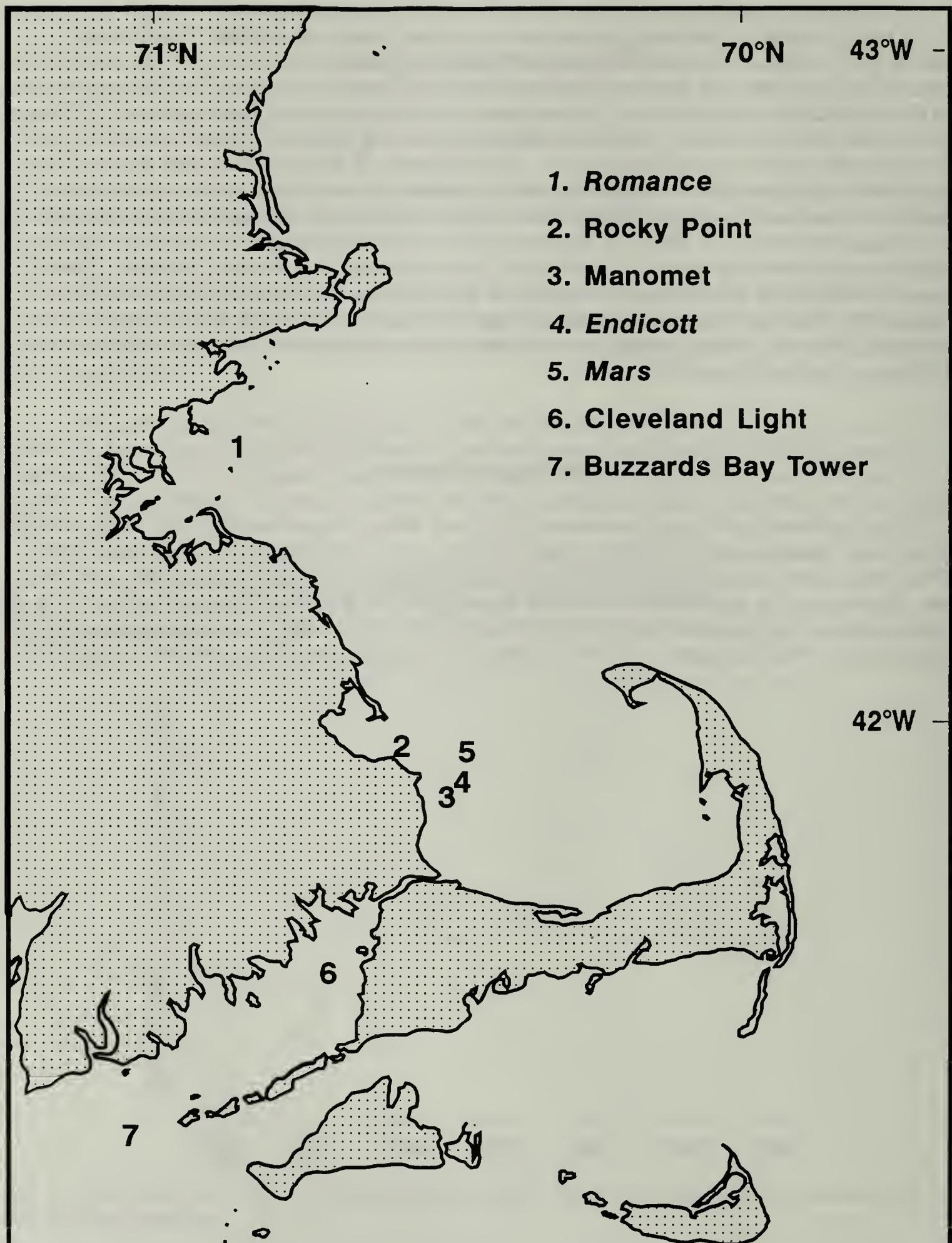
Figure 8. Map of Massachusetts with approximate locations of seven bottom
temperature monitors indicated.
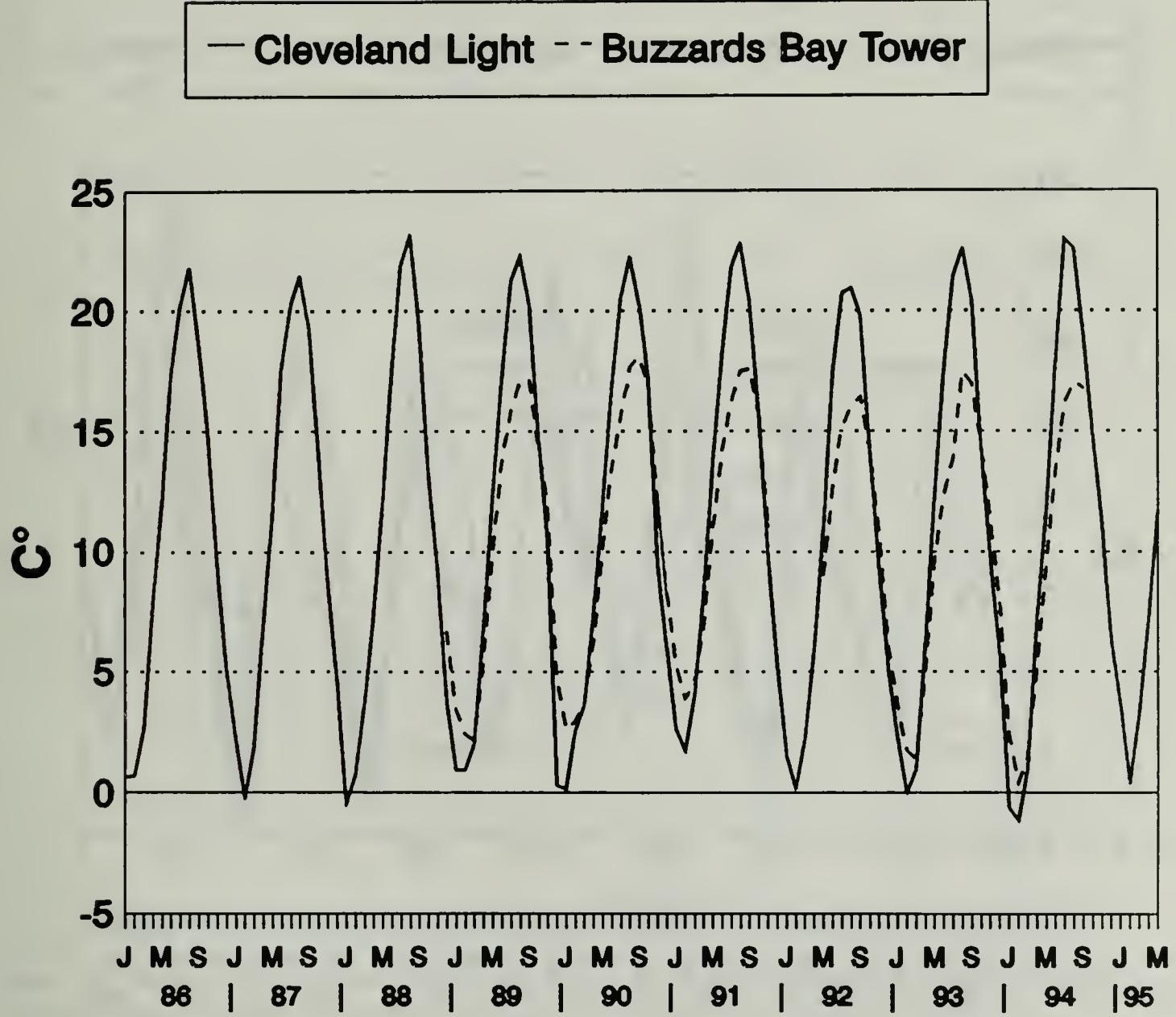
Figure 9. Mean monthly bottom water temperature at two sites in Buzzards Bay.
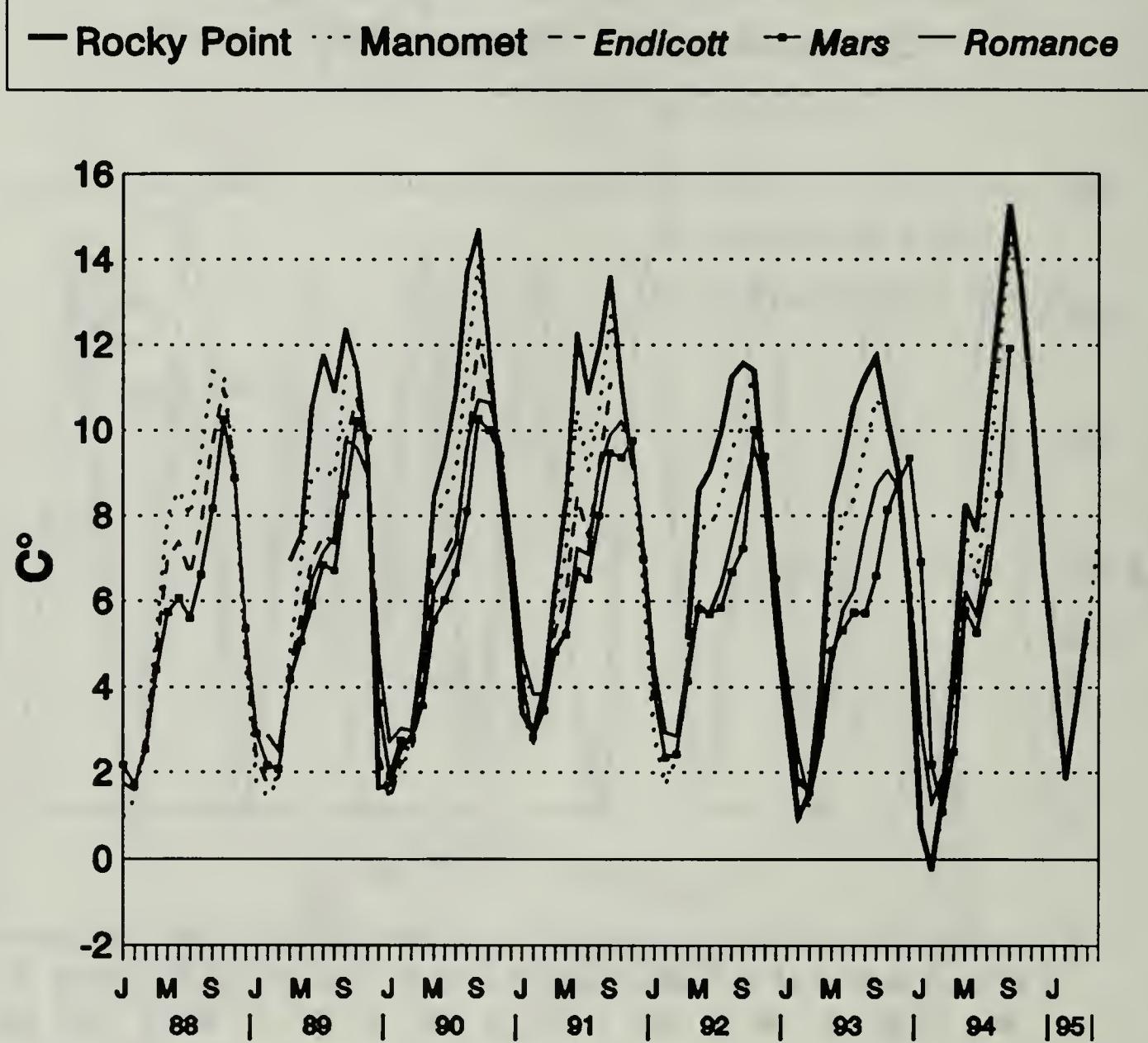
Figure 10. Mean monthly bottom water temperature at five sites in the Gulf of Maine.
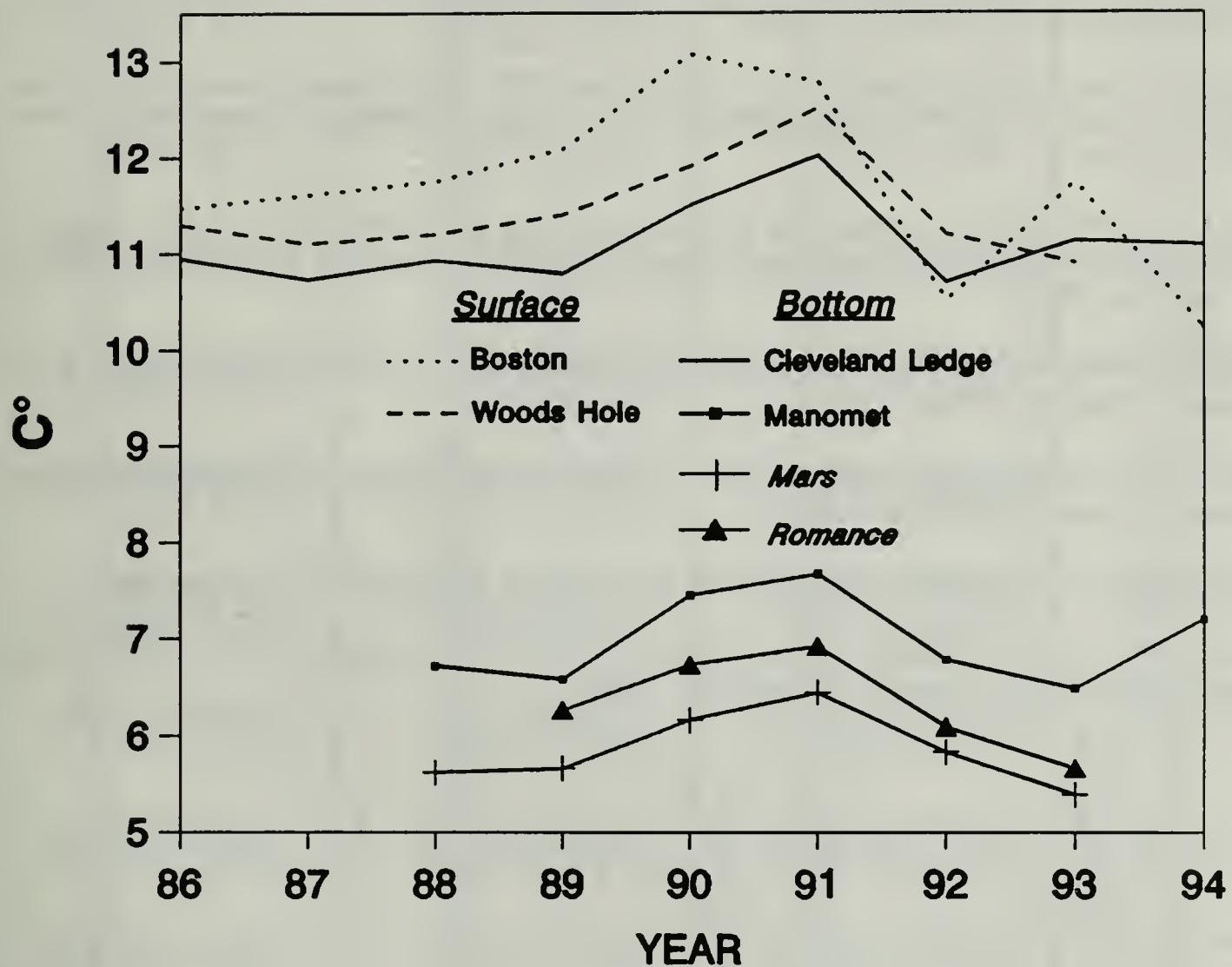
Figure 11. Mean annual bottom temperature at four sites monitored by the Coastal Lobster Project and mean annual surface temperature at two sites monitored by NOAA/NOS, 1986-1994.

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APPENDIX

Table 1. CTH'3, by state and region, for all marketable lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	0.767	0.785	0.803	0.696	0.825	0.816	0.737	0.820	0.751	0.826	0.795	0.716	0.671	0.966
Cape Ann	0.732	0.808	0.624	0.663	0.634	0.699	0.669	0.496	0.721	0.904	0.868	0.724	0.770	1.015
Beverly-Salem	0.934	0.898	0.881	0.835	0.663	0.496	0.611	0.661	0.639	0.827	0.586	0.390	0.509	0.898
Boston Harbor	---	---	---	1.108	1.254	1.096	1.058	1.057	1.123	1.224	1.160	0.734	0.750	0.725
Cape Cod Bay	0.710	0.776	0.680	0.479	0.716	0.822	0.533	0.752	0.539	0.630	0.693	0.567	0.494	1.052
Outer Cape Cod	0.808	0.824	0.765	0.598	0.856	0.811	0.937	0.861	0.923	1.219	1.148	1.339	1.021	1.105
Buzzards Bay	0.611	0.571	1.110	0.870	0.953	0.907	0.952	1.064	0.934	0.598	0.575	0.817	0.834	0.852

Table 2. CTHSOD, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	0.580	0.672	0.719	0.521	0.647	0.700	0.579	0.509	0.695	0.716	0.665	0.465	0.542	0.402
Cape Ann	0.067	0.109	0.586	0.450	0.395	0.474	0.417	0.388	0.670	0.589	0.728	0.726	0.447	0.658
Beverly-Salem	0.708	0.711	1.263	0.948	0.833	0.801	0.863	0.353	0.780	0.408	0.324	0.411	0.406	0.314
Boston Harbor	---	---	---	0.901	1.162	1.138	1.156	0.639	0.966	1.103	0.924	0.839	0.800	0.690
Cape Cod Bay	0.710	1.013	0.639	0.322	0.594	0.551	0.371	0.438	0.595	0.727	0.716	0.298	0.436	0.313
Outer Cape Cod	0.037	0.024	0.038	0.033	0.035	0.027	0.088	0.064	0.066	0.078	0.077	0.088	0.075	0.045
Buzzards Bay	0.787	0.620	0.638	0.785	0.848	1.312	0.871	1.153	1.188	1.236	1.072	0.784	1.156	0.649

Table 3. CTHAUL, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	1.473	1.701	1.624	1.389	1.705	1.899	1.873	1.736	2.297	2.216	1.996	1.460	1.720	1.389
Cape Ann	0.256	0.199	1.044	0.909	1.031	1.126	1.143	1.062	1.765	1.782	1.783	1.661	1.562	1.725
Beverly-Salem	1.855	1.713	2.526	2.504	2.567	2.435	3.482	1.862	3.477	1.867	1.563	1.502	1.540	1.717
Boston Harbor	---	---	---	2.773	3.038	3.314	3.334	1.959	3.104	3.382	2.451	2.069	2.284	2.189
Cape Cod Bay	1.544	1.680	1.345	0.825	1.337	1.512	1.031	1.442	1.742	1.921	2.086	1.065	1.334	1.033
Outer Cape Cod	0.233	0.145	0.210	0.189	0.160	0.161	0.324	0.353	0.306	0.453	0.452	0.490	0.474	0.288
Buzzards Bay	2.381	1.916	2.316	1.965	2.452	3.118	3.090	3.722	3.984	3.994	3.181	2.602	3.501	2.179

Table 4. Percent of females ovigerous, by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	5.9	7.7	10.9	9.1	8.6	9.1	9.2	8.8	10.0	10.9	9.8	11.9	14.3	10.7
Cape Ann	1.7	3.1	4.4	3.2	4.6	5.0	4.5	3.5	6.3	6.9	4.3	6.7	9.3	4.7
Beverly-Salem	1.7	2.8	1.2	0.4	1.9	1.1	1.8	1.5	1.6	1.8	3.2	3.9	5.4	2.3
Boston Harbor	---	---	---	1.4	1.2	2.0	1.7	2.0	2.1	2.7	2.8	3.0	4.4	4.7
Cape Cod Bay	3.9	3.1	3.7	3.1	3.2	2.1	3.9	2.9	3.0	3.3	5.4	6.8	6.8	7.4
Outer Cape Cod	11.1	23.0	30.3	26.8	22.3	28.9	16.9	21.4	27.4	24.5	18.3	27.7	26.8	27.3
Buzzards Bay	16.0	16.9	32.5	26.6	25.0	25.3	31.0	27.8	29.2	35.0	28.2	28.8	40.9	22.1

Table 5. CTHSOD, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	0.024	0.027	0.050	0.038	0.044	0.057	0.049	0.054	0.057	0.073	0.032	0.054	0.092	0.036
Cape Ann	0.002	0.011	0.024	0.015	0.016	0.017	0.016	0.010	0.037	0.035	0.024	0.050	0.038	0.024
Beverly-Salem	0.011	0.009	0.008	0.003	0.011	0.004	0.010	0.004	0.009	0.005	0.008	0.014	0.020	0.008
Boston Harbor	---	---	---	0.009	0.007	0.015	0.012	0.012	0.010	0.028	0.017	0.017	0.026	0.024
Cape Cod Bay	0.020	0.025	0.016	0.009	0.015	0.010	0.012	0.009	0.014	0.017	0.028	0.016	0.023	0.022
Outer Cape Cod	0.012	0.028	0.040	0.030	0.038	0.032	0.034	0.030	0.043	0.055	0.038	0.076	0.053	0.046
Buzzards Bay	0.079	0.053	0.230	0.183	0.193	0.297	0.234	0.289	0.270	0.349	0.073	0.197	0.446	0.110

Table 6. CTHAUL, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	0.073	0.078	0.179	0.116	0.133	0.167	0.183	0.189	0.211	0.282	0.140	0.227	0.319	0.143
Cape Ann	0.010	0.016	0.038	0.027	0.039	0.047	0.048	0.031	0.096	0.109	0.056	0.088	0.135	0.064
Beverly-Salem	0.025	0.033	0.016	0.006	0.033	0.018	0.036	0.021	0.039	0.023	0.049	0.047	0.067	0.048
Boston Harbor	---	---	---	0.030	0.025	0.050	0.037	0.038	0.043	0.075	0.064	0.046	0.081	0.088
Cape Cod Bay	0.048	0.048	0.040	0.024	0.040	0.031	0.038	0.034	0.039	0.055	0.091	0.056	0.078	0.075
Outer Cape Cod	0.081	0.178	0.242	0.170	0.176	0.225	0.157	0.198	0.258	0.342	0.251	0.453	0.317	0.306
Buzzards Bay	0.243	0.139	0.828	0.515	0.555	0.748	0.889	0.929	0.953	1.291	0.359	0.847	1.438	0.383

Table 7. Estimated fishing pressure index, by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	86	87	86	86	88	88	89	90	88	87	89	89	90	88
Cape Ann	91	92	87	89	87	87	88	90	84	81	90	87	83	86
Beverly-Salem	89	92	94	88	96	96	97	98	96	95	97	98	96	96
Boston Harbor	---	---	---	93	94	96	96	96	96	95	96	95	96	95
Cape Cod Bay	90	93	92	94	93	94	92	94	94	93	91	92	94	90
Outer Cape Cod	46	43	42	38	48	46	54	57	47	50	54	57	60	60
Buzzards Bay	98	96	96	94	96	97	97	97	95	94	95	97	97	98

Table 8A. Total Instantaneous (Z)* and total annual (A)** mortality estimates (Gulland, 1969) of American lobster by state and region, Massachusetts coastal waters, 1981-1994.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	1.58	1.72	1.66	1.66	1.76	1.80	1.91	1.86	1.80	1.76	1.90	1.92	1.86	2.02
	79%**	82%	81%	81%	83%	84%	85%	84%	83%	83%	85%	85%	84%	87%
Cape Ann	1.65	2.18	1.72	1.92	1.94	2.03	1.85	1.75	1.55	1.39	1.97	1.87	1.51	1.81
	81%	89%	82%	85%	86%	87%	84%	83%	79%	75%	86%	85%	78%	84%
Beverly-Salem	1.97	2.15	2.41	2.71	3.64	3.60	3.49	3.31	3.59	2.81	3.49	3.12	2.62	3.34
	86%	88%	91%	93%	97%	97%	97%	96%	97%	94%	97%	96%	93%	96%
Boston Harbor	---	---	---	2.52	3.59	2.60	2.77	2.86	2.96	3.00	3.40	3.54	3.26	3.21
	---	---	---	92%	97%	93%	94%	94%	95%	95%	97%	97%	96%	96%
Cape Cod Bay	2.53	2.69	2.42	2.52	2.31	2.83	2.26	2.74	2.43	2.46	2.33	2.58	2.60	3.10
	92%	93%	91%	92%	90%	94%	90%	94%	91%	91%	90%	92%	93%	95%
Outer Cape Cod	0.43	0.46	0.42	0.33	0.52	0.51	0.80	0.71	0.62	0.63	0.77	0.78	0.87	0.92
	35%	37%	34%	28%	41%	40%	55%	51%	46%	47%	54%	54%	58%	60%
Buzzards Bay	3.02	3.00	8.64	3.14	3.55	3.71	3.48	3.18	3.13	2.60	3.50	3.81	3.03	3.58
	95%	95%	99%	96%	97%	98%	97%	96%	96%	93%	97%	98%	95%	97%

Table 8B. Total Instantaneous (Z)* and total annual (A)** mortality estimates (Beverton and Holt, 1956) of American lobster by state and region, Massachusetts coastal waters, 1981-1994.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	1.35	1.45	1.39	1.41	1.47	1.49	1.54	1.56	1.53	1.50	1.73	1.70	1.79	1.67
	74%**	77%	75%	76%	77%	78%	79%	79%	78%	78%	82%	82%	83%	81%
Cape Ann	1.32	1.39	1.35	1.52	1.33	1.32	1.39	1.51	1.27	1.66	1.77	1.57	1.38	1.48
	73%	75%	74%	78%	74%	73%	75%	78%	72%	81%	83%	79%	75%	77%
Beverly-Salem	1.59	1.70	1.85	1.78	1.96	1.99	2.16	1.98	2.01	1.83	2.29	2.50	2.23	2.18
	80%	82%	84%	83%	86%	86%	88%	86%	87%	84%	90%	92%	89%	89%
Boston Harbor	---	---	---	1.82	1.75	1.92	1.88	1.84	1.94	1.87	2.19	2.14	2.33	2.28
	---	---	---	84%	83%	85%	85%	84%	86%	85%	89%	88%	90%	90%
Cape Cod Bay	1.64	1.92	1.72	2.07	1.88	1.92	1.78	1.87	1.97	1.95	1.96	2.01	2.14	1.93
	81%	85%	82%	87%	85%	85%	83%	85%	86%	86%	86%	87%	88%	86%
Outer Cape Cod	0.54	0.55	0.53	0.52	0.57	0.55	0.66	0.66	0.62	0.63	0.71	0.72	0.78	0.79
	42%	42%	41%	41%	43%	42%	48%	48%	46%	47%	51%	51%	54%	55%
Buzzards Bay	2.97	2.53	2.26	2.21	2.36	2.41	2.36	2.35	2.14	2.27	3.08	2.70	3.11	2.85
	95%	92%	90%	89%	91%	91%	91%	94%	88%	90%	95%	93%	96%	94%

Table 9. Instantaneous fishing mortality estimates (F), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	1.14	1.21	1.17	1.19	1.25	1.28	1.32	1.36	1.36	1.32	1.43	1.44	1.48	1.41
Cape Ann	1.33	1.47	1.11	1.33	1.28	1.22	1.30	1.37	1.12	1.04	1.50	1.32	1.14	1.25
Beverly-Salem	1.42	1.47	1.64	1.68	1.81	1.93	1.89	2.02	1.95	1.86	2.08	2.16	1.96	1.94
Boston Harbor	---	---	---	1.77	1.70	1.80	1.87	1.83	1.94	1.86	2.01	1.97	1.97	1.90
Cape Cod Bay	1.53	1.60	1.58	1.73	1.59	1.70	1.56	1.70	1.82	1.72	1.66	1.71	1.85	1.66
Outer Cape Cod	0.47	0.48	0.45	0.42	0.47	0.47	0.57	0.53	0.54	0.51	0.59	0.61	0.65	0.68
Buzzards Bay	2.32	2.13	1.94	1.80	2.04	2.11	2.08	2.06	1.95	1.97	2.34	2.26	2.39	2.31

Table 10. Estimated exploitation rate (u), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	0.62	0.64	0.63	0.64	0.65	0.66	0.68	0.69	0.69	0.69	0.68	0.69	0.69	0.68
Cape Ann	0.74	0.80	0.61	0.68	0.71	0.67	0.70	0.71	0.63	0.51	0.70	0.67	0.62	0.65
Beverly-Salem	0.71	0.71	0.75	0.79	0.79	0.83	0.77	0.88	0.76	0.85	0.82	0.79	0.78	0.79
Boston Harbor	--	--	--	0.82	0.81	0.80	0.84	0.84	0.86	0.85	0.82	0.81	0.76	0.75
Cape Cod Bay	0.75	0.71	0.75	0.73	0.72	0.75	0.73	0.77	0.79	0.76	0.73	0.74	0.76	0.74
Outer Cape Cod	0.37	0.37	0.35	0.33	0.36	0.36	0.41	0.38	0.40	0.38	0.42	0.44	0.45	0.47
Buzzards Bay	0.74	0.78	0.77	0.72	0.79	0.80	0.80	0.82	0.80	0.78	0.72	0.78	0.74	0.76

Table 11. Mean carapace length (mm), by state and region, for all marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	88.5	87.9	88.1	88.2	87.8	87.6	87.5	88.2	88.9	89.0	88.7	88.8	88.4	88.8
Cape Ann	88.6	88.3	88.3	87.9	88.4	88.3	88.0	88.3	89.3	90.3	88.4	88.8	89.6	89.6
Beverly-Salem	87.6	87.0	86.6	86.9	86.2	86.2	85.8	87.1	87.7	88.3	87.5	87.2	87.5	87.8
Boston Harbor	--	--	--	86.8	86.9	86.4	86.6	87.5	88.0	88.1	87.8	87.9	87.5	87.5
Cape Cod Bay	87.2	86.4	86.9	86.1	86.4	86.3	86.7	87.3	87.7	87.7	88.1	88.2	87.7	88.3
Outer Cape Cod	98.2	97.5	97.4	99.7	97.0	96.3	94.6	95.2	96.5	96.1	95.3	95.2	93.8	94.2
Buzzards Bay	84.7	85.2	85.7	85.8	85.2	85.3	85.3	86.1	87.4	87.0	86.4	86.9	86.5	86.5

Table 12. Mean carapace length (mm), by state and region for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	75.8	76.3	76.2	76.1	76.3	76.1	76.1	76.3	77.5	77.6	76.7	76.2	76.9	77.5
Cape Ann	78.0	77.7	77.5	77.3	77.6	77.1	75.9	77.0	78.3	78.8	78.7	77.9	78.3	78.0
Beverly-Salem	74.3	76.5	74.9	76.1	75.9	74.7	74.7	74.5	76.4	76.1	73.4	73.5	75.1	75.8
Boston Harbor	--	--	--	77.1	76.9	76.9	76.5	75.6	76.8	77.4	75.4	74.6	75.3	76.0
Cape Cod Bay	76.6	76.4	76.7	75.6	76.1	76.2	75.6	76.9	77.9	77.8	77.4	76.8	76.7	78.6
Outer Cape Cod	75.9	76.2	77.1	75.1	76.6	75.9	77.0	77.1	76.8	78.8	78.8	79.0	79.4	78.3
Buzzards Bay	75.8	75.5	76.8	76.4	76.1	76.0	76.6	76.3	77.7	77.4	76.6	77.1	78.3	77.6

Table 13. Mean carapace length (mm) of all ovigerous female American lobster, by state and region, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	88.5	87.6	88.6	87.1	87.9	88.1	87.1	87.2	88.5	88.0	86.0	85.5	85.3	86.3
Cape Ann	109.0	100.3	94.3	90.5	93.8	95.0	91.6	94.0	100.4	95.1	91.7	91.9	91.0	92.7
Beverly-Salem	80.5	84.5	85.8	83.5	85.9	83.5	81.8	83.0	85.2	85.5	83.8	81.6	82.6	83.1
Boston Harbor	--	--	--	82.1	84.0	81.3	82.3	83.7	83.0	83.8	82.0	82.0	80.8	80.9
Cape Cod Bay	86.4	83.8	85.5	84.4	85.2	86.8	87.0	84.7	86.1	85.0	83.9	84.1	83.0	84.8
Outer Cape Cod	109.8	106.1	108.0	107.1	106.9	107.3	102.5	105.2	105.4	104.6	101.9	99.2	100.7	100.0
Buzzards Bay	78.1	79.6	81.6	83.0	80.1	79.4	80.2	80.6	81.3	80.8	79.8	79.9	81.0	81.5

Table 14. Cull rate (percent), by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	10.0	10.3	10.7	14.8	18.1	20.9	17.6	18.2	19.2	18.6	18.1	18.5	20.3	21.9
Cape Ann	10.0	9.8	10.5	11.5	23.9	25.3	20.2	21.2	16.7	16.7	19.7	18.2	19.2	17.1
Beverly-Salem	8.3	8.6	10.2	20.9	23.0	30.0	24.1	26.3	28.6	27.3	28.9	22.7	28.3	30.8
Boston Harbor	--	--	--	13.3	19.3	19.1	16.9	16.3	13.8	14.7	13.5	17.2	23.4	23.0
Cape Cod Bay	11.1	10.7	10.9	15.6	18.3	21.6	16.2	17.4	22.8	20.5	18.9	18.3	18.1	19.4
Outer Cape Cod	5.7	11.3	8.9	13.0	13.4	16.1	12.6	15.0	14.0	15.5	13.2	15.7	17.3	20.1
Buzzards Bay	13.5	14.7	12.4	12.4	13.4	14.6	15.1	15.6	12.6	13.6	13.9	19.3	20.5	24.0

Table 15. Cull rate (percent), by state and region, for all legal-sized American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	8.1	9.7	9.2	12.7	14.8	17.0	14.7	15.7	14.9	15.4	15.6	17.1	17.4	21.2
Cape Ann	10.7	9.6	7.5	10.4	19.4	20.3	18.0	19.3	13.9	13.7	16.8	18.3	16.3	16.5
Beverly-Salem	4.3	7.7	7.4	15.5	19.3	22.1	17.1	21.4	18.7	25.6	22.8	19.9	24.6	25.4
Boston Harbor	--	--	--	10.1	16.2	15.8	12.9	13.1	9.9	9.9	12.3	14.0	17.5	18.0
Cape Cod Bay	9.3	9.3	10.0	13.2	14.5	18.1	15.0	15.6	12.0	16.3	17.8	16.8	16.3	21.7
Outer Cape Cod	5.3	10.3	8.1	13.3	12.5	14.9	13.1	14.3	13.3	14.1	12.8	15.3	16.4	19.9
Buzzards Bay	16.1	13.2	12.7	12.3	13.8	13.6	15.2	14.1	12.6	12.6	11.5	22.2	18.9	23.5

Table 16. Cull rate (percent), by state and region, for marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	8.2	9.9	9.2	13.2	16.2	17.6	14.7	16.0	15.2	15.6	16.1	17.6	17.6	21.9
Cape Ann	10.8	9.8	7.3	10.5	20.9	20.7	18.4	19.9	14.0	14.2	16.8	18.1	13.7	16.7
Beverly-Salem	4.4	8.0	7.4	15.6	18.5	22.2	17.2	21.3	18.9	23.8	23.1	20.0	24.7	25.5
Boston Harbor	--	--	--	10.2	16.2	15.7	12.8	13.1	9.9	9.9	12.4	14.0	17.5	18.0
Cape Cod Bay	9.3	9.3	10.0	13.2	15.9	18.2	14.8	15.6	19.1	16.2	17.8	16.7	16.2	22.3
Outer Cape Cod	5.3	10.9	8.6	14.8	12.9	16.8	13.2	14.9	13.9	14.6	14.1	16.8	17.3	21.6
Buzzards Bay	16.9	13.1	12.3	12.6	15.4	14.1	15.4	14.7	13.0	12.4	11.7	22.5	19.4	23.7

Table 17. Cull rate (percent), by state and region, for sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	11.2	11.5	11.6	16.1	20.2	23.2	18.2	19.6	21.1	20.2	19.2	19.3	21.8	22.5
Cape Ann	8.0	10.6	12.6	12.2	26.9	28.7	21.5	22.1	17.9	18.3	21.0	18.2	20.9	17.4
Beverly-Salem	10.0	9.0	11.2	22.3	24.0	31.8	25.3	28.6	30.8	29.2	31.6	23.5	29.5	33.8
Boston Harbor	--	--	--	14.5	20.5	20.0	18.0	18.0	15.2	16.4	13.9	18.3	25.3	24.7
Cape Cod Bay	11.9	11.3	11.4	17.0	20.2	23.4	16.8	18.3	24.0	21.8	19.2	19.0	18.8	17.8
Outer Cape Cod	7.8	17.9	13.5	11.7	18.6	22.8	11.0	16.9	17.1	20.7	14.3	17.1	20.2	21.3
Buzzards Bay	12.7	15.2	12.2	12.4	13.3	14.9	15.0	16.2	12.6	13.9	14.5	18.3	21.0	24.2

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Table 18. Percent trap mortality by state and region for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1994.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
State	0.15	0.04	0.22	0.15	0.18	0.20	0.10	0.15	0.12	0.17	0.37	0.08	0.13	0.22
Cape Ann	0.00	0.00	0.09	0.27	0.03	0.16	0.00	0.03	0.13	0.09	0.48	0.10	0.11	0.14
Beverly-Salem	0.00	0.00	0.00	0.00	0.04	0.22	0.03	0.19	0.14	0.29	0.41	0.13	0.19	0.13
Boston Harbor	--	--	--	0.00	0.03	0.03	0.23	0.09	0.03	0.04	0.01	0.03	0.06	0.04
Cape Cod Bay	0.00	0.02	0.03	0.00	0.00	0.02	0.15	0.00	0.02	0.05	0.02	0.02	0.02	0.00
Outer Cape Cod	0.46	0.22	0.23	0.48	0.40	0.85	0.27	0.66	0.47	0.62	0.35	0.24	0.30	0.58
Buzzards Bay	0.62	0.00	1.13	0.43	0.76	0.25	0.01	0.18	0.11	0.18	1.74	0.10	0.29	0.71

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